Electronic Processes in Liquid Helium

W.F. Schmidt[1], E. Illenberger[1], A.G. Khrapak[2], Y. Sakai[3], and K. Yoshino[4]

[1]*Institute for Physical Chemistry, Freie Universität Berlin, 14195 Berlin, Germany*
[2]*Institute for High Temperatures, Russian Academy of Science, Moscow, Russia*
[3]*Dept. of Electrical Eng., Faculty of Engineering, Hokkaido University, Sapporo, Japan*
[4]*Department of Electronic Engineering, Graduate School of Engineering, Osaka University, Osaka 565-0871, Japan*

Liquid helium represents the most simple non-polar dielectric liquid. Its properties have been studied extensively [1]. Especially, the investigation of the interaction of excess electrical charges introduced into the liquid have been carried out by physicists, chemists, and electrical engineers. Besides its importance as a model for the liquid state, liquid helium has found important applications as coolant and insulant in superconducting devices.

Of special interest are the interactions of excess electrons with the liquid surface or with the He-atoms in the bulk of the liquid. In both casaes, the strong repusion between the excess electron and the closed electron shell of the helium atom is the determining factor. If electrons are sprayed onto the surface of lHe they become trapped and at higher concentrations form a regular pattern which eventually leads to a caving in of the surface and the formation of a multi-electron bubble with a radius of the order of 10μm to 100μm. Between 10^5 to 10^7 electrons are then trapped at the inner surface of the bubble [2,3].

If electrons are injected into the liquid directly, either from a photocathode or by irradiation with high energy radiation, they form microscopic voids of approximately 2nm radius. Their drift in an applied electric field appears as that of a massive ion.

It was found for liquid neon, where also a strong repulsion between the excess electron and the closed electron shell of the neon atoms exists, that the injection process proceeds in three stages: First, the electron is injected into a delocalized state where it is occasionally trapped at density fluctuations. Second, if it remains sufficiently long at such a site the surrounding atoms will move away and the lectron becomes selftrapped in a bubble. The lifetime in the delocalized state was measured for lNe to be between 1ns and 100ns, depending upon temperature and applied electric field strength [4]. The time for bubble formation, once the electron has found a suitable potential well, is or the order of ps [5]. Third, the final state of the electron is the bubble state.

For liquid helium, similar conditions for the injection process as in liquid neon should exist. But no direct measurements of the delocalized electron state have been carried out. In our previous experimental work we had measured the mobility of electron bubbles in liquid helium as a function of the electric field strength. Excess electrons were injected from a metal cathode in contact with the liquid helium. The data are shown in Fig. 1. While at low electric field strengths the drift velocity is proportional to the applied electric field, at higher values of the field a superlinear dependence is observed. In a recent publication [6] we analyzed this apparent increase of the drift velocity under the assumption that the injected electrons first travel part of their way to the anode in a conduction band (delocalized state) before becoming localized in bubbles. From the data we estimated a lifetime τ of the electrons in the delocalized state of approximately $\tau = 5$ns at T = 3.86K and E = 72kV/cm.

Electric breakdown of lHe occurs at much higher electric field strengths, where the lifetime in the delocalized state is expected to be even longer, so that a Townsend type of electron multiplication in the liquid phase may be considered as the initiating step of the breakdown process. Several factors, which do not support this hypothesis, have to be considered. Yoshino et al.[8] found that the cathode plays a governing role in the initiation of the breakdown process. This can be interpreted by considering the cathode as the source of starter electrons. The electrons move in the strong electric field and their mean energy quickly reaches values of several eV. Due to collisions they dissipate the energy in the liquid leading to regions of low density allong the path of the electrons. The latent heat of evaporation of lHe is very small, a few J/g. In these gas-like regions the conditions for a gaseous Townsend process may be fulfilled and the breakdown process proceeds along these channels.

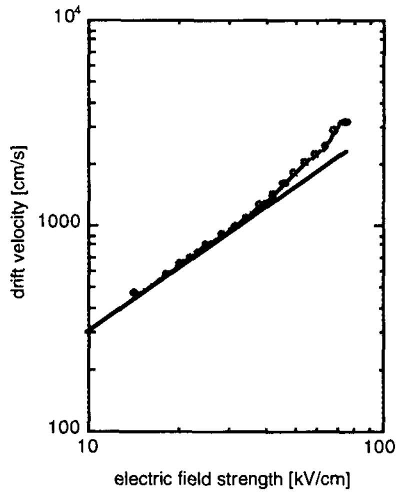

Fig. 1: Drift velocity of electron bubbles in lHe as a function of the electric field strength, after ref. [7]

References

[1] J. Wilks and D.S. Betts, "An Introduction to Liquid Helium", Clarendon Press, Oxford 1987

[2] U. Albrecht and P. Leiderer, Can. J. Phys. **65**, 1536 (1987)

[3] W.F. Schmidt, "Liquid State Electronics of Insulating Liquids", CRC Press, Boca Raton 1997

[4] Y.Sakai, W.F. Schmidt, and A.G. Khrapak, Chem. Phys. **164**, 139-152 (1992)

[5] M. Rosenblit and J. Jortner, J. Phys. Chem. **A101**, 751 (1997)

[6] W.F. Schmidt, E. Illenberger, A.G. Khrapak, and Y Sakai, J. Chem. Phys. **115**, No 21 in press

[7] Y. Sakai, H. Böttcher, and W. F. Schmidt, J. Electrostatics **12**, 89 (1982)

[8] H. Fujii, I. Kaizaki, K. Yoshino, and Y. Inuishi, J. Phys. D **12**, 1555 (1979)